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EVALUATION OF THE F/A-18 HEAD-UP-DISPLAY FOR RECOVERY FROM UNUSUAL ATTITUDES

Jerry Guttman

Aircraft and Crew Systems Technology Directorate
Man-Machine Integration Division
HFE Technology Development Branch
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974

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Maintaining situational awareness is a critical task in piloting an aircraft. Focusing on spatial orientation, the attitude displays provide information necessary for the pilot to control the aircraft's position in space. In the F/A-18 aircraft the Head-Up Display (HUD) is the primary attitude indicator. This ~~The present~~ study compared an electrically drawn attitude direction indicator (ADI), the current F/A-18 HUD, and the concurrent use of the ADI and HUD for recovery from unusual attitudes.

~~The~~ results indicated significantly faster recovery times for the ADI. Reasons may be attributed to the superiority of the color coding of the ADI for sky and ground over the dashed and solid pitch lines used for ground/sky coding on the HUD format. Pilot preferences were split between using the ADI alone and the concurrent use of the HUD and ADI. Reasons for this preference include the use of the ADI as a convenient crosscheck and reduction of visual workload when using the HUD and ADI concurrently compared to using the HUD alone.

The results from this study, which employed an electrically drawn ADI, parallel those found in earlier experiments comparing an electromechanical ADI to the F/A-18 HUD ~~(Kinsley et. al., 1985)~~. The ~~results~~ suggest that a centrally located ADI in the F/A-18 cockpit would aid pilots during unusual attitude recovery.

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INTRODUCTION

Maintaining situational awareness is a critical task in piloting an aircraft. At least three factors compose a naval aviator's overall awareness during flight: (1) tactical awareness of an air combat or high threat environment, (2) spatial orientation of the plane's relationship to the ground, and (3) navigational awareness of the aircraft's position on course.

Focusing on spatial orientation, measures of airspeed, altitude, and attitude provide the information necessary for the naval aviator to assess the aircraft's immediate position in space. The naval aviator can receive this information through the auditory and kinesthetic senses. For example, the sound of the Radar Altimeter Warning System (RAWS) provides aural cues indicating altitude above ground level. Kinesthetic cues from the control stick and rudder pedals provide indications of the aircraft's pitch, roll and yaw. G-force vectors acting on the naval aviator during flight reflect the roll, climb and dive rates of the aircraft. Vision, however, is the primary sensory channel used to assess spatial orientation.

Visual cues give the naval aviator precise information about the aircraft's position in space. Two classes of visual cues are available to the naval aviator: (1) those resulting when visual flight rules (VFR) are in effect and (2) those which occur when instrument flight rules (IFR) are implemented. When flying in VFR conditions, the out-of-the cockpit visual scene provides the primary information for maintaining spatial orientation. The size and resolution of man made and geographical features of the earth provide indications of altitude. The horizon is the primary attitude reference, providing a reference line for estimating the aircraft's angular relationship to the earth. While flying in IFR conditions, the cockpit instrumentation provides the necessary flight control information for spatial orientation. The naval aviator must visually scan the displays, integrate and process flight

control information before updating the position of the controls. During IFR conditions, when external visual cues are lost, the secondary orientation senses (vestibular organs, kinesthetic senses) may give false motion cues or may fail to perceive subtle changes in attitude (Kirkham, et. al. , 1978). When the naval aviator incorrectly assesses the attitude of the aircraft, he or she becomes spatially disoriented. Spatial disorientation can result in a degradation of pilot performance, or loss of the aircraft and/or pilot. Therefore the timely and accurate visual identification of attitude information from the cockpit instruments is critical.

ATTITUDE DIRECTIONAL INDICATOR

The conventional attitude directional indicator (ADI) is a primary flight reference for a variety of civil and military aircraft. The ADI provides an artificial horizon, during instrument flight, allowing the pilot to orient the pitch and roll of the aircraft without visual reference to the earth's horizon. Color coding is used to differentiate pitch attitude above and below the horizon. Black or brown are common colors for designating the ground and white or blue are often used to designate the sky. The contrast between the ground and sky colors defines the artificial horizon. Comparing the aircraft symbol to the pitch scale denotes the angular relationship of the aircraft to the horizon.

The design of the ADI follows the display principle of pictorial realism. This principle is an assertion that a display should present a spatial analog of the real world (Roscoe, Corl and Jensen, 1981). The ADI provides a spatial analog by pictorially displaying the earth's horizon in relation to the aircraft. Pictorially realistic aircraft displays allow the pilot to use a highly learned set of rules about the world to interpret the displayed information. This <u>direct</u> comparison between the display and the real world is

not possible with symbolic displays.

F/A-18 HEAD-UP-DISPLAY

The head-up-display (HUD) is the main reference for attitude information in the F/A-18 aircraft. Pitch and roll information are shown by a pitch ladder and roll scale. Airspeed and altitude are presented in a digital format. Heading is determined by reading a moving tape readout along the top of the display. These readouts are arranged in an integrated fashion so they can all be seen within the design eye envelope, requiring a minimum of eye and head movement.

PRELIMINARY RESEARCH

In response to a questionnaire administered at the Naval Air Test Center (Jewitt & Merriman, 1984), one third of the F/A-18 pilots gave below average ratings for the HUD as the primary attitude reference for quick interpretation of unusual attitudes. More specifically, 6 pilots reported that the pitch lines on the pitch ladder were difficult to interpret in nose high and nose low attitudes. Reasons for this include (1) rapid movement of the pitch lines and (2) the dashed pitch lines below the horizon line look very similar to the solid lines above the horizon.

Kinsley, Warner and Gleisner (1985) compared the F/A-18 HUD pitch ladder to an ADI for time to recover from unusual attitudes. Two experiments were conducted. In the first experiment, static formats of the F/A-18 pitch ladder and an ADI were projected onto a screen in front of the subject. Each subject was presented with 18 different pitch and roll orientations for each format. The subject viewed the slide, determined the orientation presented on it and made a control input with a joystick to reorient the display to straight and level. Decision times and errors (control reversals) were measured. The results showed that decision times for the ADI were significantly faster than the pitch ladder. There were no significant

differences in the percentage of errors made with either format.

The second experiment tested the formats dynamically in a medium fidelity, ground based simulator. The stimuli for this experiment were actual display formats presented in real time. The symbology displayed on the HUD was identical to that which is displayed in the most decluttered mode of the F/A-18. The ADI was an actual standby ADI from an F-14. The computer system oriented the attitude indicator to a preset disorientation. The subject's task was to reorient the attitude indicator back to straight and level. Decision times and recovery times were measured by the computer. The results of this experiment indicated that the use of the ADI resulted in faster recovery times than the pitch ladder format. There were no differences in decision times. The results of both experiments suggest that the inclusion of an ADI located within the central field of view would aid in unusual attitude recovery and improve pilot spatial orientation.

Currently, the ADI gyro in the F/A-18 cockpit is small and poorly located (slightly above pilot's right knee). Advancements in display technology may allow the ADI to be placed in a better location within the cockpit. Recent research and development efforts for the F/A-18 include an advanced up-front control (UFC) panel for the HUD. Included in this new UFC is a three inch by three inch flat panel display (see figure 1). Another component of the UFC is a symbol generator capable of producing an electronically generated ADI. If this representation of the ADI ball on the flat panel display maintains the same dynamic and visual characteristics of an electromechanical ADI, it could provide an centrally located attitude indicator requiring little eye translation from the HUD. The current research effort investigated whether the addition of an electronically generated ADI, displayed directly below the HUD would aid pilots in recovery from unusual attitudes.

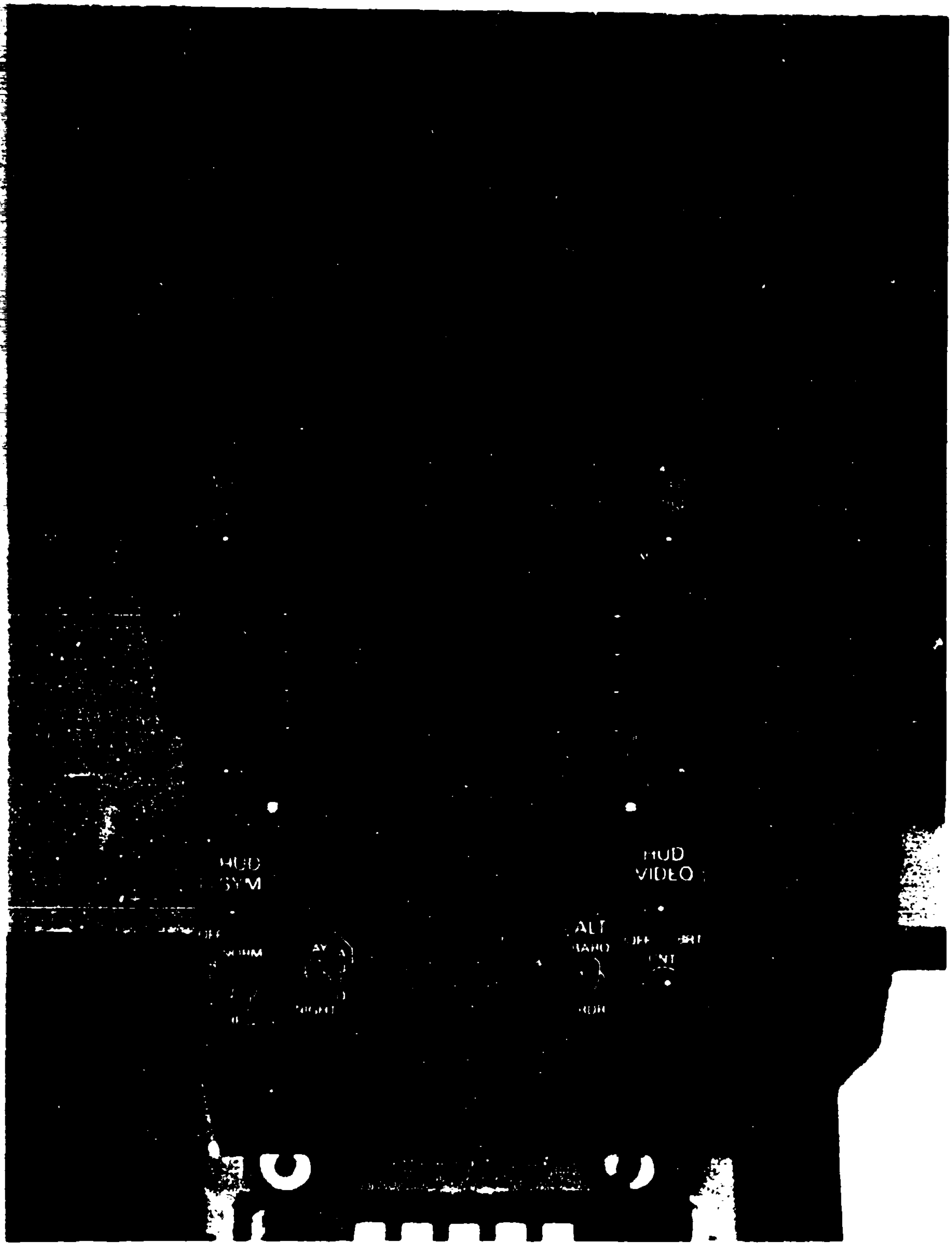


Figure 1 - F/A-18 Advanced Up-Front-Control Panel
(Numbers above horizon line are for illustrative purposes only and were not used in this experiment.)

METHODOLOGY

The present study compared three display formats for their ability to aid pilots in recovery from unusual attitudes. The first format was the graphic representation of an ADI (figure 2). The second format was the F/A-18 HUD (figure 3). The third format was the concurrent use of the HUD and the ADI (figure 1). The experimental hypotheses were that (1) the concurrent use of the HUD and the ADI would result in faster decision and recovery times than the use of the HUD alone and (2) the use of the ADI alone would result in faster decision and recovery times than the use of the HUD alone.

SUBJECTS

Ten naval aviators participated in this evaluation. Five of these were naval aviators who had at least fifty hours using the HUD as a primary flight instrument. The remaining five naval aviators had no previous experience using the HUD as a primary flight instrument. The aircraft these naval aviators were rated in is presented in Table 1.

Table 1

Flight Hours for Naval Aviators Participating in F/A-18 HUD Evaluation

Aircraft	Average Number of Flight Hours	Number of Pilots
A-7	524	5
F-4	1167	3
F-14	839	4
F/A-18	219	4
P-3	1700	2

Note: 8 naval aviators were experienced on more than one aircraft.

Figure 2

Attitude Directional Indicator

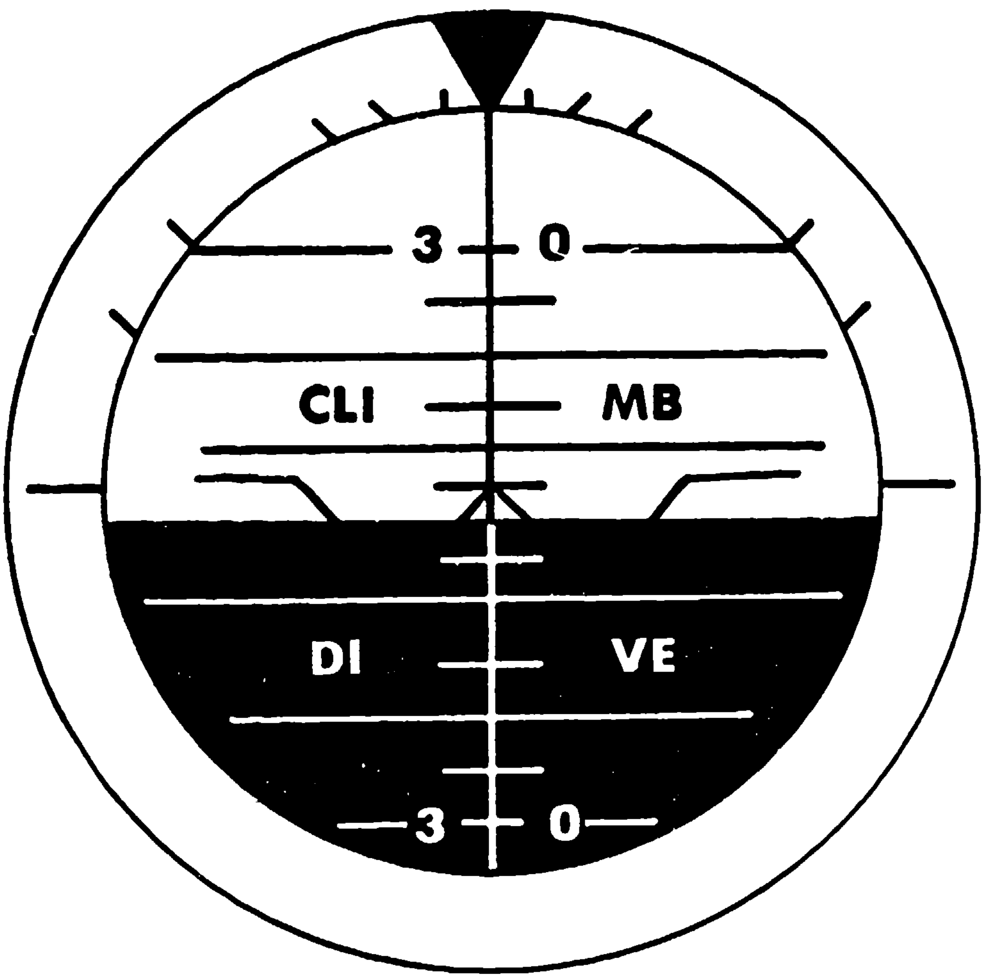
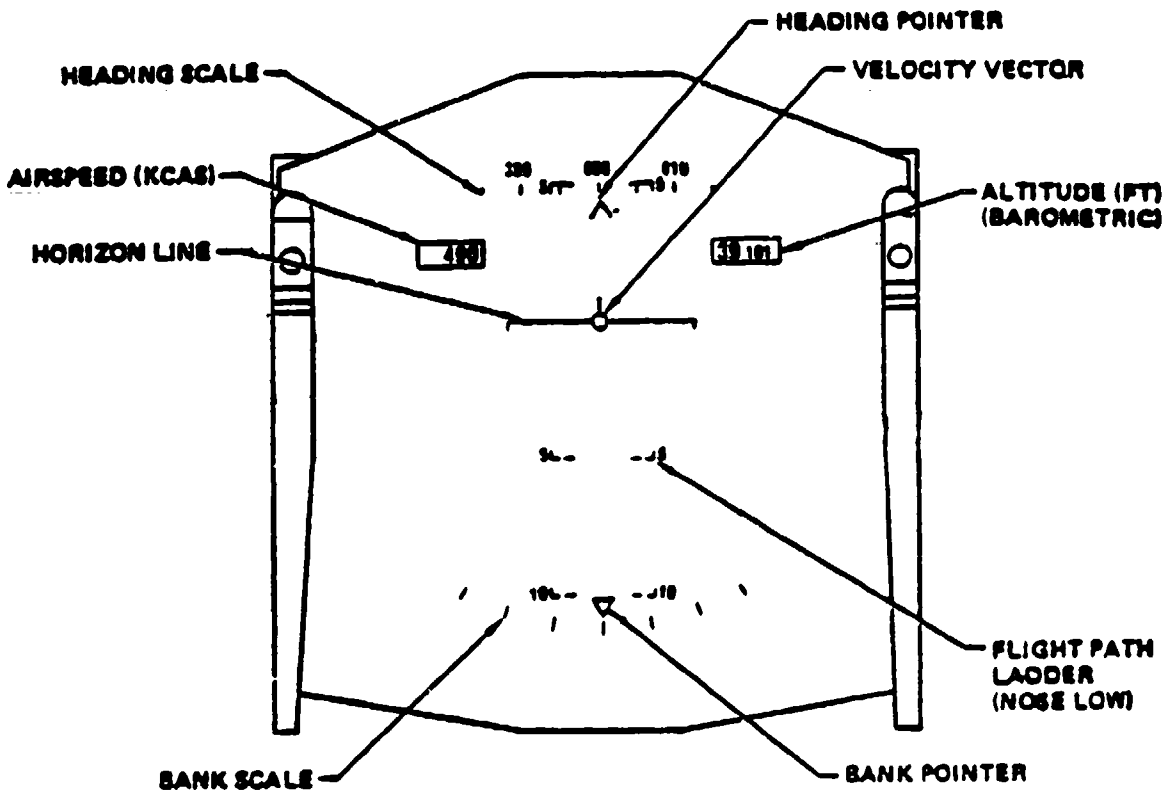


FIGURE 3

F/A-18 HEAD-UP-DISPLAY SYMBOLOGY



HUD BASIC SYMBOLOGY

COCKPIT SIMULATOR

The experiment was conducted in a generic ground based cockpit simulator located in the Man-Machine Integration Laboratory at the Naval Air Development Center (Figure 4). The components consisted of a Digital Equipment Corporation (DEC) Vax 11/785 computer, a DEC PDP 11/44, an Evans and Sutherland PS-300 symbol generator, and Adage RS-3000 symbol generator, and a Bowmar programmble control panel. The HUD symbology was presented as a collimated image on an actual HUD combiner. The ADI was presented on a Cathode Ray Tube (CRT), and beamed via a mirror system on to a 3 inch by 3 inch mirror placed on the back of the HUD where the Up-Front Control (UFC) would normally be. This display surface simulated the flat panel currently in development for the Advanced UFC for the F/A-18 (Figure 2). In the simulation, computers were used to generate the dynamic display formats and to collect pitch, roll, and reaction time information. A schematic of the simulation system is presented in figure 5.

DISPLAY FORMATS

The display formats for this experiment were computer generated. The displays were dynamic in the sense that they could display changes in the aircraft's position in space caused by the pilot's control stick and throttle inputs. The aerodynamic and performance characteristics of the F/A-18 were modeled by software residing on the PDP 11/44. The control/display relationship was therefore influenced by the aerodynamic characteristics of the simulated aircraft.

The symbology presented on the HUD was identical to the symbol set displayed in the most decluttered mode on the current F/A-18 HUD (see figure 3). The pitch ladder and velocity vector were presented along with a roll scale, heading indicator, digital airspeed and altitude indicators. The pitch ladder had pitch lines for every 5 degree change in pitch. Pitch lines below

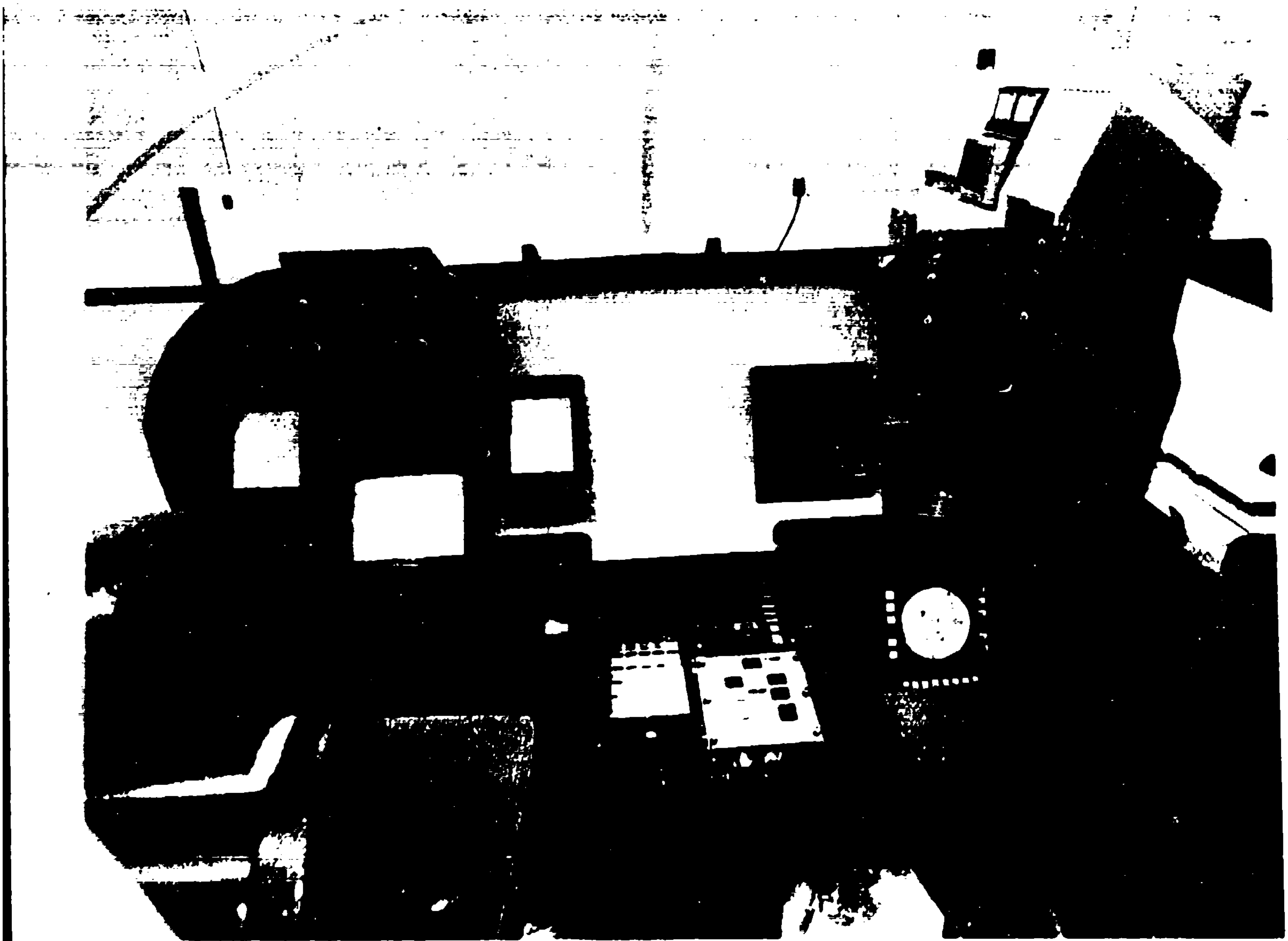
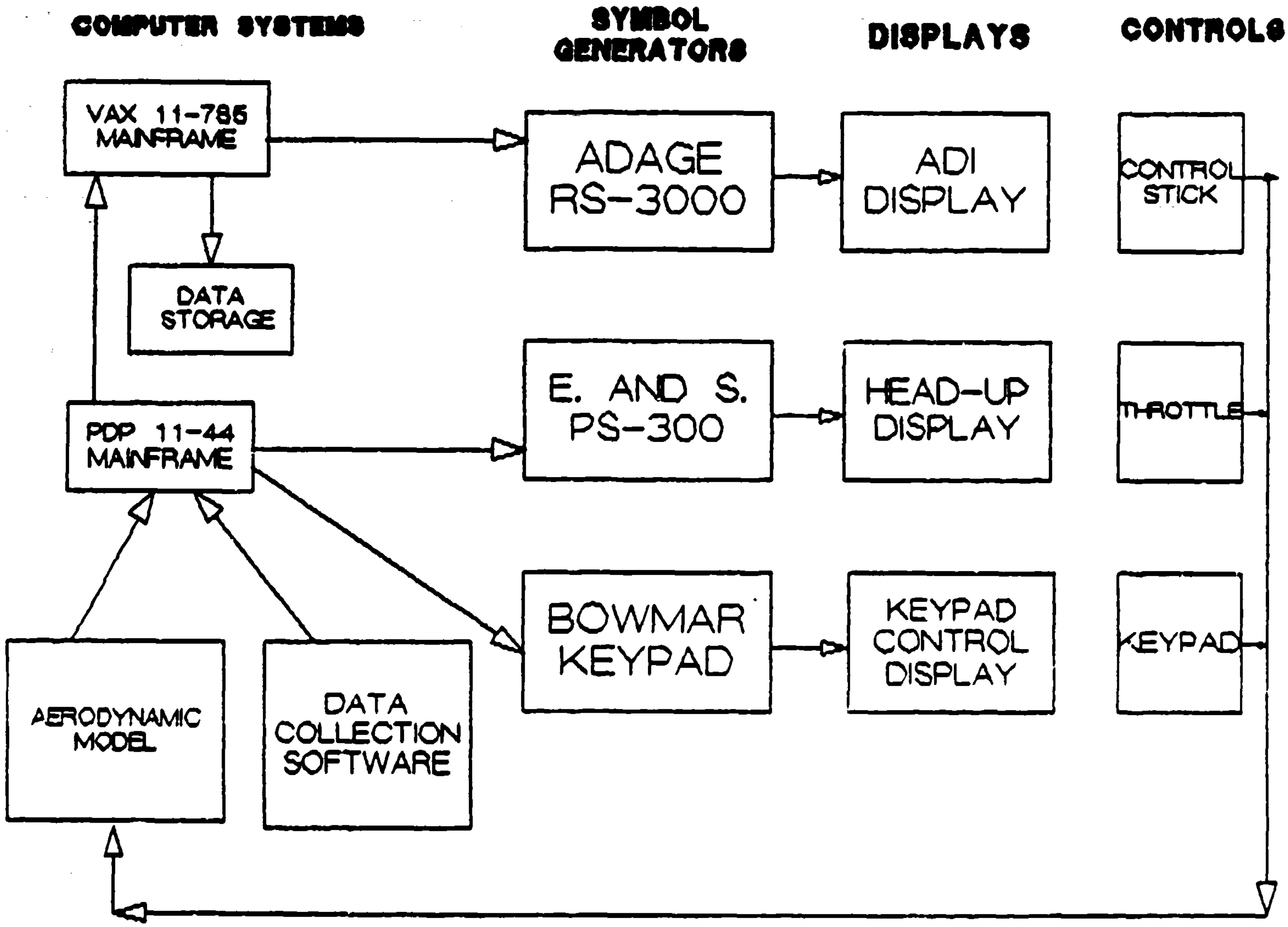


Figure 4 - Cockpit Simulator

Figure 5

Simulation Configuration



the horizon line were dashed and lines above the horizon were solid. The pitch lines also increase in angle with increases in the pitch of the aircraft in a 1:2 ratio. For example, if the aircraft was pitched up 60 degrees, the pitch lines would be angled 30 degrees and pointed down towards the horizon. The slope of the pitch lines was always towards the horizon line.

The ADI used in this experiment simulated the pictorial and dynamic properties of an ADI gyro. The pitched up half was colored light grey and the pitched down half was black. The area where the 2 colors met served as the artificial horizon. The ADI displayed both pitch and roll scales. The pitch scale had markings for every five degree change in pitch. Thirty and 60 pitch angles were denoted by "60" and "30" numeric symbols. The roll scale consisted of a fixed scale with a moving pointer and had markings for every 30 degrees roll across the upper half of the ADI. A static aircraft symbol was located in the center of the display. Attitude information was gained by comparing the aircraft symbol to the orientation of the artificial horizon.

The ADI display and HUD pitch ladder had several features in common. One common characteristic was that they were both "inside out" displays, meaning that they both had a stabilized aircraft symbol and a moving artificial horizon line. The horizon moved in the direction opposite to the control stick input. For example, a left control stick movement caused the horizon line to tilt to the right. Comparison of the aircraft symbol to the moving horizon represented the aircraft' attitude. This type of attitude display is referred to as an earth referenced or aircraft stabilized display (Johnson and Roscoe, 1972).

Both indicators could present a wide variety of different attitude orientations, far more than could be practically evaluated in an experimental setting. A subset of the possible orientations were selected. These included steep climb and dive orientations and situations in which the aircraft was

inverted. There were three values of pitch employed for this experiment: 0, 55, and -55 degrees. Six values of roll were used: 0, 60, 120, 180, -60, and -120 degrees. All possible combinations of these pitch and roll values were tested resulting in 18 unique pitch and roll orientations.

PROCEDURE

The experimental design was a 4-factor, mixed design with repeated measures on 3 factors. The between subjects comparison was experience using the HUD as a primary flight instrument. The repeated measures were: (1) pitch, (2) roll, and (3) display format. Within each HUD experience level, each subject received all possible combination of pitch, roll, and display format.

Each naval aviator was given a "preflight" briefing before flying the simulator. Included in this briefing were explanations of the various controls and displays and their locations in the cockpit. The naval aviators were shown viewgraphs depicting each display format to be evaluated. Descriptions and explanations of these formats were given and naval aviators had the opportunity to ask questions. At this point a demographic questionnaire was administered.

After this briefing, the naval aviator was seated in the right seat of the side-by-side cockpit and began flying the simulator. During this familiarization phase, no data was collected nor was any experimental intervention introduced. This period of time was included to allow naval aviators to become familiarized with the locations of the controls and displays in the simulator, the control-display relationships and the appearance of the attitude indicator formats as they appeared in a number of different orientations. Practice trials began when the naval aviator reported that he/she felt comfortable flying the simulator. Eighteen practice trials were included, 6 trials for each of the 3 display formats. These trials were included to familiarize each naval aviator with the experimental procedure. No data was collected during these practice trials.

The experimental session consisted of 54 trials. There were 18 trials accounting for all possible combinations of pitch and roll, for each of 3 display formats. All of the possible pitch and roll orientations were presented on an attitude display for one format before a new format was presented. The order of display format presentation was counterbalanced across subjects in the experiment. The order of presentation of pitch and roll combinations was randomized for each display format presentation. The counterbalancing and randomization procedures were included to counteract any learning effects that may have occurred during the experimental session.

An experimental trial began by: (1) the experimenter alerting the naval aviator that the trial about to begin, and (2) the experimenter initiating the trial. Once the trial began, the naval aviator assumed control of the simulation. The naval aviator maintained the orientation of the attitude display at a straight and level orientation. Once straight and level, the naval aviator was required to scan a chart and enter waypoint data using a keyboard located inside the cockpit. When he/she pressed the enter key after entering the elevation of the waypoint, the computer automatically reoriented the attitude indicator to a pre-selected pitch and roll orientation.

The naval aviator's task at this point was to use the control stick to reorient the aircraft back to straight and level. Once the naval aviator decided that the attitude display indicated that the aircraft was back to straight and level, he or she squeezed the trigger located on the control stick. This stopped the simulation. The computer automatically set new parameters and the next trial was initiated.

Five minute rest periods were taken after each format had been tested under all pitch and roll combinations. Before continuing to the next format, each naval aviator completed a questionnaire which required him/her to assess

various features of the display he/she had just used (See Appendix I). At the end of the experiment, each naval aviator participated in a structured interview and was asked which display they preferred overall and why (See Appendix II).

DEPENDENT MEASURES

Two dependent measures were recorded (1) decision time (2) recovery time. Decision time for this experiment was defined as the amount of time that elapsed between pressing the "enter" key on the keyboard and the initiation of a control stick movement. Recovery time was defined as the amount of time that elapsed between the initiation of a control stick movement and the time at which the aircraft entered the envelope between -5 and 5 degrees pitch and roll. The computer system tracked the pitch and roll of the aircraft during the experimental session and recorded this information every .10 second.

RESULTS

DECISION TIMES

Mean decision times and standard deviations for each level of each factor are presented in Table 2. An Analysis of Variance (BMDP, 1983) revealed a main effect of pitch ($F = 57.72$, $p < .0001$) and a main effect of roll ($F = 14.73$ $p < .0001$). Duncan's multipe range test for mean comparsions for pitch showed that the 55 and -55 pitch values were only significantly different from 0 ($p < .05$), but not from each other. The same post-hoc comparison for the roll factor indicated that 0 degrees roll was significantly different from each of the other five roll values ($p < .05$), but none of the other roll values were

significantly different from each other.

Table 2

Means and Standard Deviations for Decision Times

Factor	Mean	Standard Deviation
Experienced	2.40	0.79
Non-experienced	2.36	0.84
Format		
HUD	2.42	0.79
ADI	2.37	0.90
HUD + ADI	2.35	0.76
Pitch		
0 degrees	1.98	1.01
55 degrees	2.67	0.66
-55 degrees	2.48	0.55
Roll		
0 degrees	1.77	1.36
60 degrees	2.48	0.66
120 degrees	2.47	0.56
180 degrees	2.57	0.59
-120 degrees	2.48	0.60
-60 degrees	2.50	0.61

Note: All decision times are expressed in seconds.

RECOVERY TIMES

Mean recovery times and standard deviations for each level of each factor are presented in Table 3. An analysis of variance showed significant main effects for pitch ($\underline{F}$ = 130.71 $p<.0001$), roll ($\underline{F}$ = 7.20 $p<.0001$), and format ($\underline{F}$ = 11.37 $p<.001$). Post-hoc comparisons of the means for these factors are presented in Table 4. Results of these tests show that recovery was significantly faster using the ADI compared to the HUD. All 3 pitch conditions were significantly different from eachother with the 55 degree condition taking the longest, the -55 degree next, and the 0 degree pitch condition resulting in the fastest recovery times. The results of the roll factor indicate that the 0 degree condition was significantly different from the other five conditions, but the other roll values were not significantly different from each other.

In addition to the main effects, the analysis resulted in a significant pitch by format interaction (F=7.69 $p<.001$). This interaction is graphically shown in figure 6. Analysis of the simple main effects revealed significant differences in recovery times at the 55, and -55 degree pitch conditions, but no differences between the 3 formats at the 0 degree pitch condition. At the 55 and -55 degree pitch values, all of the differences between recovery times were significant. The use of the ADI resulted in the fastest recovery times, the concurrent use of the HUD and ADI had the next fastest, and the HUD had the slowest recovery time.

Table 3

Means and Standard Deviations for Recovery Times

Factor	Mean	Standard Deviation
HUD Experience		
Experienced	7.22	4.54
Non-experienced	8.51	6.29
Format		
HUD	9.69	6.76
ADI	6.23	3.77
HUD + ADI	7.88	5.38
Pitch		
0 degrees	3.18	2.88
55 degrees	12.89	5.12
-55 degrees	7.74	3.57
Roll		
0 degrees	6.68	6.64
60 degrees	7.72	5.80
120 degrees	8.41	4.42
180 degrees	8.44	5.15
-120 degrees	8.36	5.44
-60 degrees	2.50	5.92

Note: All recovery times are expressed in seconds.

TABLE 4

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST

FOR MEAN COMPARISONS

EXPERIMENTAL CONDITION = FORMAT

HUD	HUD + ADI	ADI
9.69	7.88	6.23

EXPERIMENTAL CONDITION = PITCH

55 DEGREES	-55 DEGREES	0 DEGREES
12.89	7.74	3.17

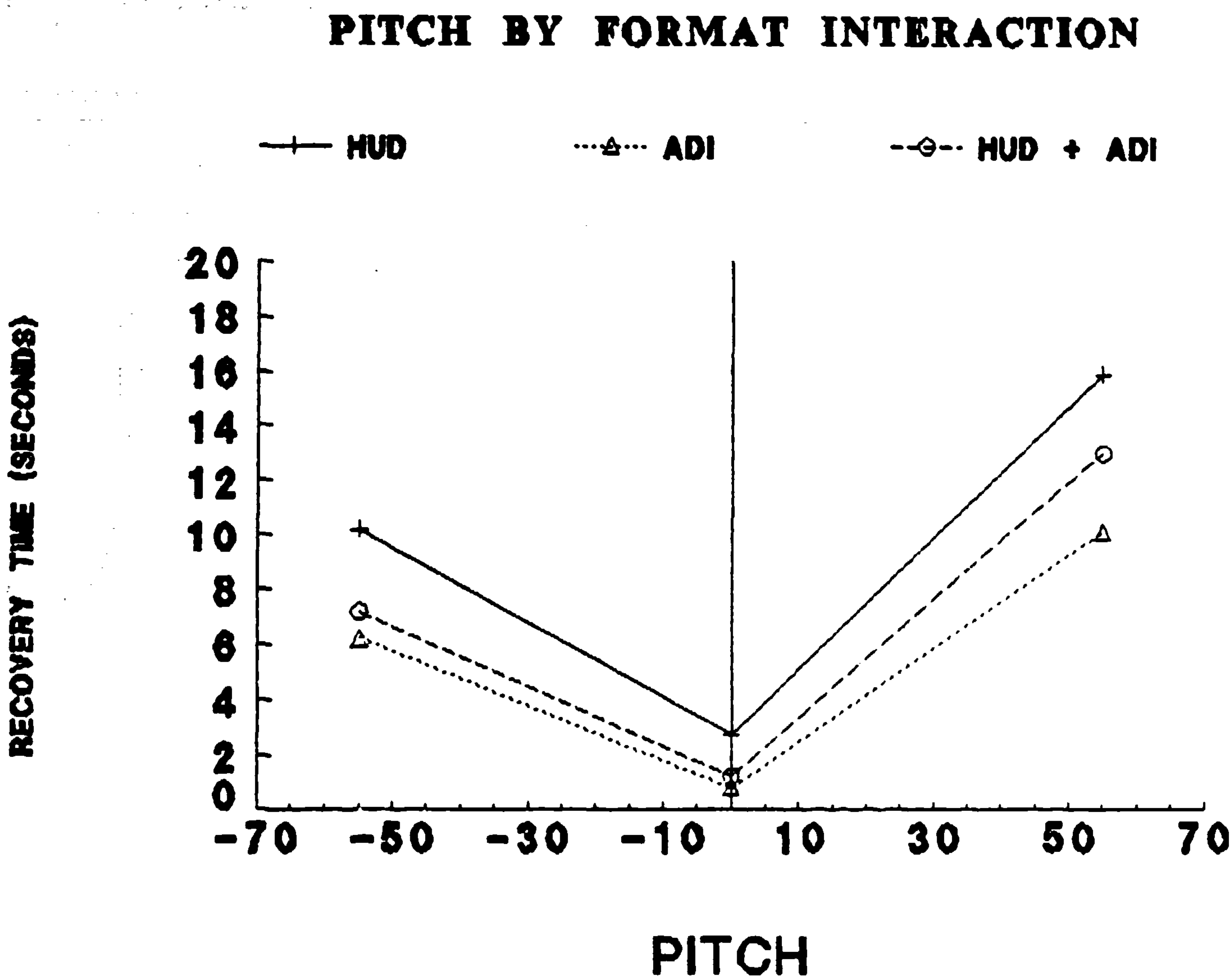
EXPERIMENTAL CONDITION = ROLL

0 DEGREES	60 DEGREES	120 DEGREES	180 DEGREES	-120 DEGREES	-60 DEGREES
6.68	7.72	8.41	8.44	8.36	7.99

Note: Those means underlined by a common line are not significantly different from each other.

Figure 6

Pitch by Format Interaction



INDIVIDUAL QUESTIONNAIRE DATA

After all experimental trials were completed on a display format, naval aviators were given a questionnaire which allowed them to rate the extent to which they agreed with statements about the display format. A sample questionnaire is in Appendix I. The ratings were based on a five point scale where:

1 = strongly disagree

2 = moderately disagree

3 = neutral

4 = moderately agree

5 = strongly agree

A lower score indicated a less favorable rating for the display format on that particular dimension. Ratings for each question were averaged across the ten naval aviators. The average ratings for each dimension and display format are presented in Table 5.

In addition to the ratings, naval aviators were asked to state which features of the display format helped them assess the attitude of the aircraft. Eight naval aviators commented that the color coding for sky vs. ground helped them assess the aircraft's attitude when using the ADI. Eight naval aviators commented that the angled pitch lines which point to the horizon were helpful for attitude assessment when using the HUD. Finally, when using both displays concurrently both of these features were helpful, but in different stages during unusual attitude recovery. Six naval aviators reported that they used the horizon pointing pitch lines on the HUD for initial

Table 5

Individual Questionnaire Ratings for Display Formats

Item	HUD	ADI	HUD + ADI
Legibility of the pitch lines	2.90	4.10	3.70
Ease of controlling the aircraft	2.20	4.20	3.80
Ease of determining aircraft's pitch	2.60	4.30	3.90
Ease of determining aircraft's roll	3.90	4.40	4.70
Pitch ladder compression	3.00	3.60	3.80
Visibility of horizon line	2.90	4.50	4.60
Ease of deciding how to recover	3.00	4.30	4.50
Usefulness as a crosscheck	N/A	N/A	4.30
Usefulness in an operational aircraft	3.70	4.30	4.50

Note: Pitch ladder compression refers the number of pitch lines visible on the display at a given time (e.g. HUD compression = 15 degrees, ADI compression = 70 degrees).

assessment of the closest path to the horizon and subsequently transitioned to the light/dark contrast on the ADI for the final stages in the recovery.

Naval aviators were also asked what features of the three display configurations hindered their ability to assess the aircraft's attitude. For the ADI, 4 naval aviators commented that when the indicator was all light or dark, it was hard to tell the shortest path to the horizon. Six naval aviators reported difficulty discerning between the solid and dashed pitch lines on the HUD used to code for pitch above and below the horizon. There was little consensus on negative features of using both displays together. All comments

on the individual questionnaires are located in Appendix I.

PREFERENCE QUESTIONNAIRE DATA

At the end of the experimental session, all naval aviators participated in a structured interview. During this interview, naval aviators were asked to state which displayed format they preferred overall, the display they least preferred and reasons for their preferences. Table 6 lists the tallies for most and least preferred display formats.

Table 6

Most and Least Preferred Display Formats

Format	Most preferred format	Least preferred format
HUD	0	7
ADI	4	2
HUD + ADI	6	0

Note: 1 Naval Aviator had no preference for least preferred display.

The reasons for preferring the ADI alone were due to the color coding for up vs. down and for the its smoother response to control inputs. The reasons for preferring the HUD + ADI include the ability to crosscheck for attitude information (3 naval aviators), and the ability to use the HUD for initial attitude assessment followed by a transition to the ADI for the final stages of the recovery (3 naval aviators). Naval aviators preferred the HUD the least because of confusion as to whether the aircraft was up or down (4 naval aviators), and the rapid movement of the pitch lines during recovery (2 naval aviators). A complete listing of reasons for naval aviator preferences is located in Appendix II.

During the structured interview each naval aviators was asked to give comparative ratings for various features of each display format. For this rating scale, the HUD was chosen as the standard and given a fixed value of 100 for each rating dimension. Each naval aviator was asked to assign a number to the two other conditions that should be proportional to the relative usability of the HUD. For example if a naval aviator felt a format was twice as usable as the HUD it would be assigned a number twice as large as the HUD (i.e. 200). On the other hand, if a naval aviator felt that a format was one-half as usable as the HUD on a particular dimension, he/she would assign a number to that format that was one-half as large as the standard (i.e. 50). Table 7 presents the results of these items for all 3 display formats.

Table 7

Mean Comparison Ratings

Questionnaire Item	Display Formats HUD	ADI	HUD + ADI
Providing least amount of visual workload	100	211	162
Ease in controlling aircraft	100	273	226
Ease in deciding how to reorient aircraft	100	203	205
Ease in comprehending pitch	100	184	169
Ease in comprehending roll	100	141	139
Best pitch scale compression	100	135	150
Legibility of pitch lines	100	106	125
Legibility of symbols	100	121	128
Ease in distinguishing horizon line	100	225	215
Ease in attaining a snapshot attitude assessment	100	255	253

Note: HUD has been assigned a value of 100 for each questionnaire item. ADI and HUD + ADI conditions were assigned numbers to reflect their relative usability with respect to the HUD (i.e. 200 refects a usability twice that of the HUD, 50 reflects a usability 1/2 that of the HUD).

DISCUSSION

The current evaluation showed that the electronically generated ADI resulted in significantly faster recovery times compared to the current F/A-18 HUD format. Improvements were noted whether the ADI was used alone or concurrently with the HUD. The reasons for this result include (1) the superiority of color coding on the ADI for denoting sky and ground vs. solid and dashed lines on the HUD and (2) A slower, yet more controllable rate of movement of the pitch scale on the ADI compared to the rapid movement of the HUD pitch ladder. Other advantages of the ADI include an easily distinguishable horizon line and ease in obtaining a snapshot assessment of the aircraft's attitude.

The concurrent use of the HUD and the ADI proved to be complementary during unusual attitude recovery. During recovery from extreme pitch attitudes, the strengths of each format compensated for weaknesses in the other. For example, when the aircraft was placed in a nose high or nose low attitude, the ADI was nearly all one color which reduced the number of horizon pointing cues available. The horizon pointing pitch lines on the HUD, however, gave clear directions as to the horizon's location. After initial control movements, the color contrast on the ADI provided confirmation of the horizon's location and provided the necessary information for completion of the recovery. It is interesting to note that despite the scan created by having to look at 2 displays, the concurrent use condition was rated more usable than the HUD in terms of visual workload. This result suggests that the addition of pictorial information may have reduced the workload associated with processing the digital and symbolic information presented on the HUD.

The ADI alone condition resulted in significantly faster recovery times overall and was significantly faster than the other two conditions for recovery

from nose high and nose low attitudes. Several naval aviators commented, however, that this display did not provide the altitude and airspeed readouts that a naval aviator would need in for an actual unusual attitude recovery. Additional research would help to determine whether the ADI alone would still produce superior recovery times with the addition of airspeed and altitude readouts. In addition, the results of this evaluation failed to provide any evidence that, for unusual attitude recovery, HUD experienced naval aviators were able to use the HUD any better than naval aviators with no previous HUD experience.

The results of this investigation parallel the findings of Kinsley et. al. (1985) who found that an electromechanical ADI produced significantly faster recovery times than the F/A-18 HUD format. The current study showed the same result with the use of an electronically drawn ADI. These studies suggest that the use of an electronically drawn ADI on the flat panel display of the UFC would convey information as effectively as an electromechanical ADI placed in the same location.

In summary, the results of this study indicate that the addition of a centrally located ADI display in the F/A-18 would improve pilot performance during unusual attitude recovery. In addition, the ADI would allow pilots to conveniently crosscheck for attitude information displayed on the HUD.

Based on the results of this investigation, it is recommended that design specifications be developed for the inclusion of an ADI format for the advanced UFC. This would include specifying the design of the format and symbology as well as identifying the task and functional requirements associated with the ADI display. Parameters for this analysis would include suggestions as to how the ADI should be integrated with other requirements for this display panel (i.e. communication, navigation). Another concern is determining what attitude sensor would send information to this display. Ideally, the attitude

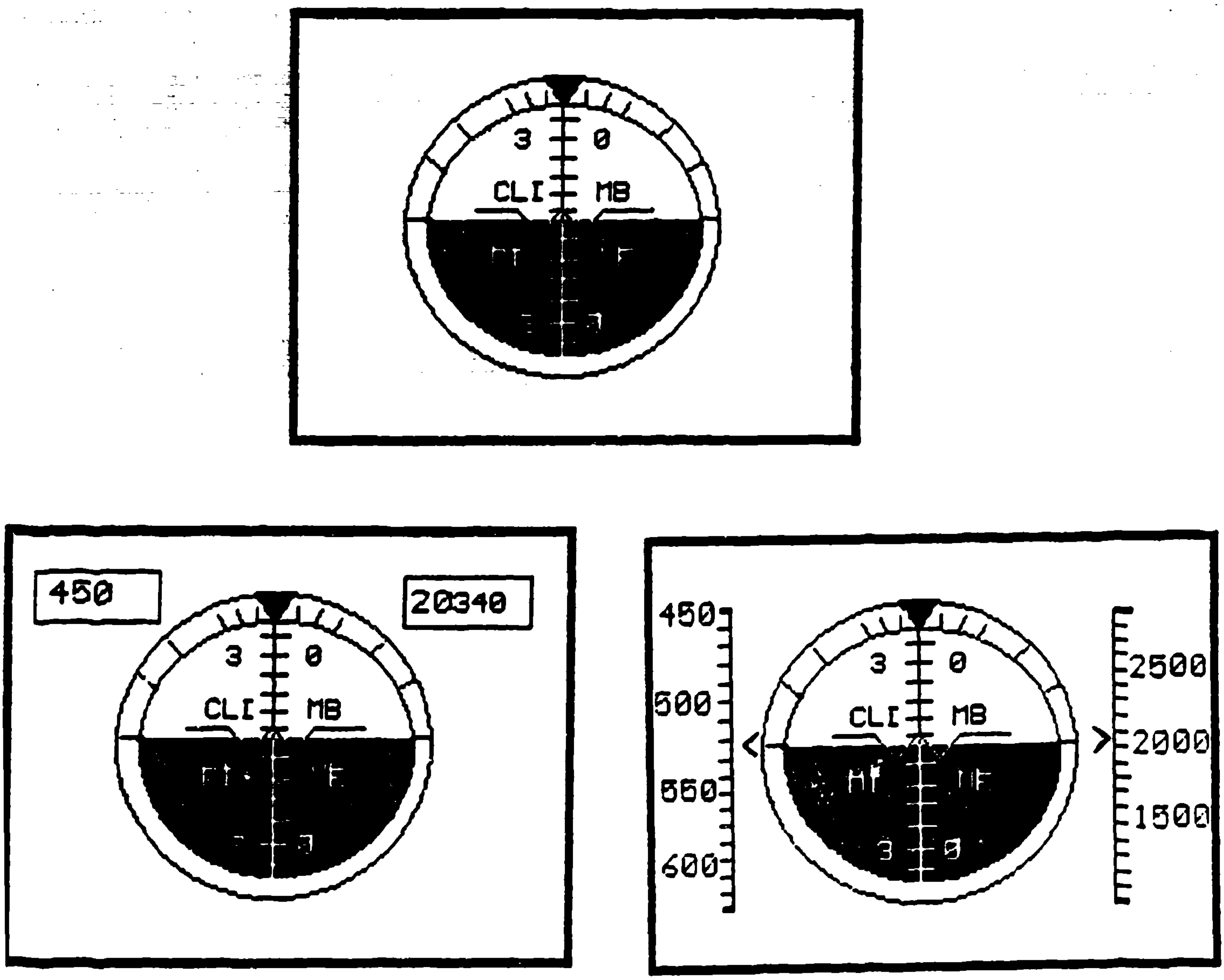
information on the HUD and ADI would be provided from independent sensors, so pilots would have a true crosscheck. However, the feasibility of this needs to be determined.

Continued research and development of the ADI display is needed. More specifically, the inclusion of airspeed and altitude readouts on the ADI display may improve the pilot's ability to maintain his/her spatial orientation. Research is needed to determine what the impact these readouts would have on pilot performance during unusual attitude recovery. Another related question is what would the format of these readouts would look like? The current airspeed and altitude readouts on the HUD are in a digital format. They provide precise information for stabilizing airspeed and altitude, but show small trends very quickly and can be difficult to interpret during rapidly changing airspeeds and altitudes. A comparison of digital vs. traditional moving tape readouts would allow the costs/benefits of each type of format to be evaluated. Figure 7 shows the 3 formats proposed for this experimental comparison.

The location of the advanced UFC is a valuable area in the F/a-18 cockpit. The display surface has the potential to reduce pilot workload by decreasing the time spent scanning the head down displays for information. Continued experimental evaluations of this display surface would allow the Navy to develop new display formats for the UFC and evaluate their usefulness.

Figure 7

3 Formats for Experimental Evaluation



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APPENDIX I
OVERALL AND INDIVIDUAL QUESTIONNAIRES

PILOT ________

OVERALL COMPARISON QUESTIONNAIRE

1. Which display or display arrangement did you prefer overall? Why?

____

____

2. Which display or display arrangement did you least prefer? Why?

____

____

3.

This part of the questionnaire is designed to obtain your opinions regarding the relative usability for the 3 attitude displays. To give you a standard reference for you judgments, a value of 100 has been assigned to the HUD alone presentation mode. Please assign a number to the other two presentation modes which represents their relative usability with respect to the HUD. The values you assign to the ADI and ADI + HUD modes should be proportional to the relative usability of the standard. For example if you feel a display is twice as usable as the standard, it would be given a number twice as large as the standard (e.g. 200). If on the other hand, you feel it is one-half as usable, it would be given a value of 50.

	ADI	HUD	HUD + ADI
a) Providing the least amount of visual workload.	______	100	______
c) The display's responsiveness to the control stick.	______	100	______
f) Deciding how to re-orient the aircraft to a straight and level attitude.	______	100	______
g) Ease of comprehending the pitch of the aircraft.	______	100	______
b) The compression of the pitch scale.	______	100	______
e) Legibility of pitch lines.	______	100	______

d) Readability of the numeric and alpha-numeric symbols.	______	100 ______	______
h) Ease of comprehending the roll of the aircraft.	______	100 ______	______
i) Ease in distinguishing horizon line.	______	100 ______	______
j) Ease of obtaining a quick snapshot assessment of the aircraft's attitude	______	100 ______	______

4. What were the advantages or disadvantages of using the pitch ladder compared to using the pitch ladder and artificial horizon together to determine the attitude of the aircraft?

____

____

5. What were the advantages or disadvantages of using the pitch ladder alone compared to using the artificial horizon alone to determine the attitude of the aircraft?

____

____

INDIVIDUAL QUESTIONNAIRE PILOT ______ FORMAT ______

1. What features of this display helped you best assess the attitude of the aircraft?

____

____

2. What features of this display made it difficult to assess the attitude of the aircraft?

____

____

3. What steps did you go through to reorient the aircraft to a straight and level attitude?

____

____

PLEASE CIRCLE ONE SCALE POINT ONLY

4. The numeric and pitch line symbols presented on this display were legible and easy to read.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1	2	3	4	5

5. Controlling the pitch and roll of the aircraft was difficult using this attitude indicator.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1	2	3	4	5

6. It was easy to determine the pitch of the aircraft from this display.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1	2	3	4	5

7. The compression of the pitch ladder was ideal for recovery from nose high and nose low attitudes.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1 ------	2 ------	3 ------	4 ------	5

8. It was easy to determine the degree of roll of the aircraft using this attitude indicator.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1 ------	2 ------	3 ------	4 ------	5

9. The horizon line was clearly visible on this attitude indicator during recovery from an unusual attitude.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1 ------	2 ------	3 ------	4 ------	5

10. When the aircraft was in an attitude other than straight and level, it was difficult to decide how to reorient the plane back to straight and level.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1 ------	2 ------	3 ------	4 ------	5

11. It was difficult to cross-check for attitude information between displays.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1 ------	2 ------	3 ------	4 ------	5

Couldn't crosscheck _____

12. This type of display format would be useful in an operational aircraft.

STRONGLY DISAGREE	MODERATELY DISAGREE	NEUTRAL	MODERATELY AGREE	STRONGLY AGREE
1 ------	2 ------	3 ------	4 ------	5

APPENDIX II

INDIVIDUAL QUESTIONNAIRE COMMENTS

1. <u>Features of the HUD which helped naval aviators assess aircraft attitude</u>

Angled pitch lines which point to the horizon (8 naval aviators)

Tail pointers at the end of pitch lines which point to the horizon (3 naval aviators)

Whether numbers were right side up or upside down (2 naval aviators)

Roll axis on pitch ladder (2 naval aviators)

Comparing pitch ladder to the waterline symbol (1 naval aviator)

Solid lines for nose high, dashed for nose low (1 naval aviator)

2. <u>Features of the ADI which helped naval aviators assess attitude</u>

Color coding for sky vs. ground (8 naval aviators)

Large size, Centrally positioned, Bright numbers (1 naval aviator)

Familiar with gyro attitude (1 naval aviator)

3. <u>Features of the concurrent use of ADI and HUD which helped naval aviators assess attitude</u>

Using horizon pointing pitch lines on HUD initially, light and dark on ADI for pull to the horizon (6 naval aviators)

Availability of second attitude source for crosscheck (2 naval aviators)

Roll axis of HUD, sky/ground contrast of ADI (1 naval aviator)

Immediate attitude recognition with the ADI (1 naval aviator)

4. <u>Features of the HUD which hindered attitude assessment</u>

Dashed lines at times difficult to discern from solid lines (6

naval aviators)

No artificial horizon (2 naval aviators)

The waterline symbol was too small (2 naval aviators)

Numbers are difficult to read (1 naval aviator)

Too much digital information (1 naval aviator)

5. <u>Features of the ADI which hindered attitude assessment</u>

None (4 naval aviators)

When the indicator was all light or dark it's hard to tell the shortest path to the horizon (4 naval aviators)

Numbers and and shades of color with words on it make it difficult to determine horizon direction. (1 naval aviator)

Numbers difficult to read when indicator is moving (1 naval aviator)

6. <u>Features of the concurrent use of the HUD and ADI which hindered attitude assessment</u>

High attitude climb was tough, having small dark portion on ADI would be nice (2 naval aviators)

Too much information on HUD, no problem with ADI (2 naval aviators)

No problems (2 naval aviators)

Dashed vs solid pitch lines on HUD (2 naval aviators)

The numbers on both the HUD and ADI are difficult to read when in motion and the HUD pitch lines are not easily distinguishable when in motion (1 naval aviator)

APPENDIX III

OVERALL COMPARSION QUESTIONNAIRE COMMENTS

1. Reasons why naval aviators preferred the ADI the most

Artificial horizon is helpful, up is grey down is black, color coding provides instant up/down recognition.

Smooth response

HUD was disorienting

Pictorial display format of the ADI is superior to digital HUD format.

2. Reasons why naval aviators preferred the concurrent use of the HUD and ADI the most

Liked both for ability to crosscheck (3 naval aviators)

HUD provides instant nose attitude by pitch lines pointing to the horizon, ADI lets you know up from down (3 naval aviators)

3. Reasons why naval aviators preferred the ADI the least

No comment

Took much concentration and time to determine position

4. Reasons why naval aviators preferred the HUD the least

HUD is great for everything except unusual attitude recovery

Confusion with up and down
High rates of movement of pitch lines

Difficult in mild unusual attitude to determine that you were in an unusual attitude
Difficult to determine up from down
Rapid movement of the pitch lines

HUD was disorienting during IFR

Difficulty in finetuning
Not being sure whether you were up or down
Difficulty reading numbers on pitch lines

Too much digital information
Trouble reading numbers on pitch lines

Confusion determining up from down
Waterline was not distinct

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